The selection, installation, and startup of a large, adjustable-frequency paper machine sectional drive

William F. Baker, Thomas Cortes, and Robert P. Derrick

The linerboard machine is a nominal 6 m wide with a rated maximum drive speed of approximately 790 m/min. The machine drive uses 20 ac-drive motors and 19 inverters, totalling approximately 5000 kW.

Our company operates a total of 16 paper machines in four mills in Virginia, South Carolina, Georgia, and Alabama. Six of the machines have line-shaft drives run by steam turbines, whereas the other ten have electric sectional drives. Five of these sectional drives have been installed within the past four years, and the company expects to purchase a similar number of machine drives over the next six years.

The Savannah mill, the oldest mill in the company, operates seven machines, producing unbleached kraft paper and linerboard. All of the machines are fourdriniers a nominal 6 m wide (236 in.). Six of the machines have electric sectional drives. Three machines are now powered from motor-generator sets, one machine has a static analog dc drive, one has a modern static digital dc drive, and one has a modern static digital ac drive.

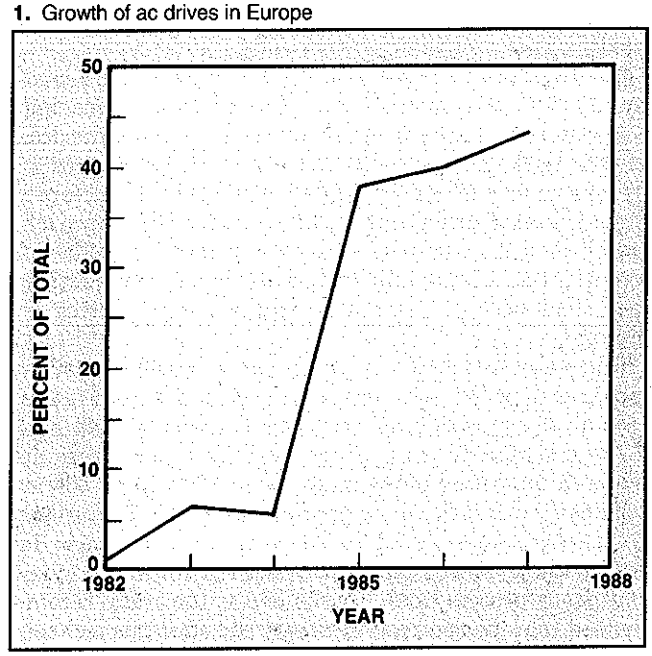
Drive study

The company installed three new machine drives in the period of 1984–1986. Although these installations were successful, some of the startups were difficult and troublesome. In the fall of 1985, senior management asked the corporate engineering division to initiate studies to find the most modern and dependable paper machine drives in service worldwide.

Among the conclusions reached in the study, digital regulators were found to be more accurate, providing far better diagnostics for troubleshooting. They also have much less downtime than analog drives. All modern drives today offer digital regulators.

Second, foreign suppliers of drive systems have not successfully penetrated the U.S. market for a number of reasons. The American mills demand drives that comply with U.S. design and manufacturing practices and will not willingly consider drives without established local service support. This attitude allows qualified domestic suppliers to dominate the U.S. market. Digital dc drives designed and manufactured overseas do not offer sufficient technological advantages to be attractive in the U.S. market place.

1. Growth of ac drives in Europe



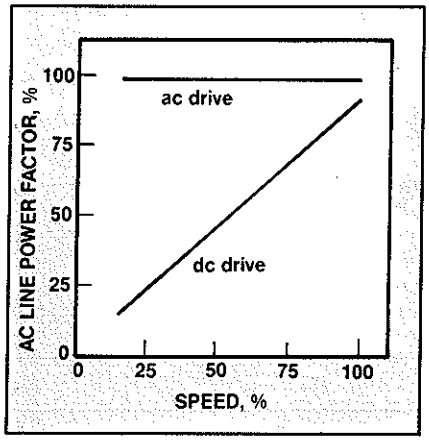
A major source of downtime and repair expense on even modern dc digital drives are the dc motors. In some installations, up to half of the electrical downtime, and 80–90% of the repair costs on the drive can be attributed to the dc motor.

Since 1981, European mills have been successfully using digital ac sectional machine drives. The ac motors have a much lower failure rate than dc motors and cost far less to repair.

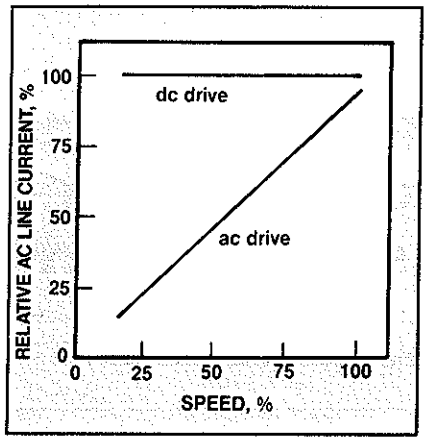
In the period of 1978–1981, U.S. mills experimented with small-horsepower ac sectional drives on cylinder machines, tissue machines, and towel machines. Electron-

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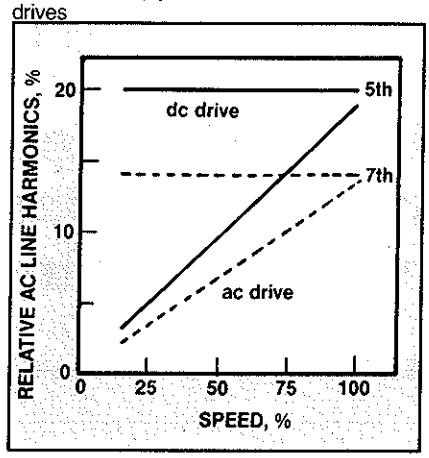
2. Relative power factors of ac vs. dc drives



3. Relative ac line current of ac vs. dc drives



4. Power supply line harmonics of ac vs. dc drives



ic devices with suitable power were not available at that time for large sectional drives. Major U.S. drive suppliers did not pursue the technology again until 1987.

Since about 1982, digital ac drives, manufactured in Japan, have been used with paper machines in the Pacific basin.

The study also disclosed that Allen Bradley Co., in a joint venture with Stromberg Oy of Helsinki, was preparing to introduce ac paper machine drives to North America. At that time, the company had been successfully using Stromberg technology for digital dc drives manufactured in the United States for about three years. This approach had allowed the company to become a major supplier of drives for the U.S. paper industry. Stromberg, on the other hand, had become the major supplier of ac drives in Europe.

The study concluded that ac paper machine drives appeared to be the drive technology of the future. **Figure 1** shows the growth of ac drives in Europe. Almost half of the machine drives produced by Stromberg were ac drives in the period of the study, 1985-1986. Over 500 ac sections are in service on paper machine drives in Europe; by contrast, approximately 90 ac sections are now in service in the United States on paper machines and other continuous process lines. Consequently, the study recommended that the company seriously consider this technology for the next machine drive.

No. 6 paper machine drive

The Savannah mill's No. 6 paper machine was installed in 1953. Producing linerboard of 26-90-lb, its initial speed range was 400-1600 ft/min. The original drive was a General Electric Co. multi-generator drive with electronic Amplidyne™ regulators and BC46™ tachometers. The machine and drive underwent numerous rebuilds between 1965 and 1985. In 1966, Reliance digital tachometers and static regulators were installed on the original generators. Between 1968 and 1978, several wet-end rebuilds, with Westinghouse static power supplies, increased the machine drive speed range to 122-610 m/min (400-2000 ft/min).

The machine drive had thus become a "hybrid orphan" with obsolete or discontinued equipment throughout. Service was difficult to obtain. The 35-year-old dc motors and generators were a particularly troublesome source of electrical downtime and maintenance expense.

I. Required cable amperage capacity for the motor feeder cable

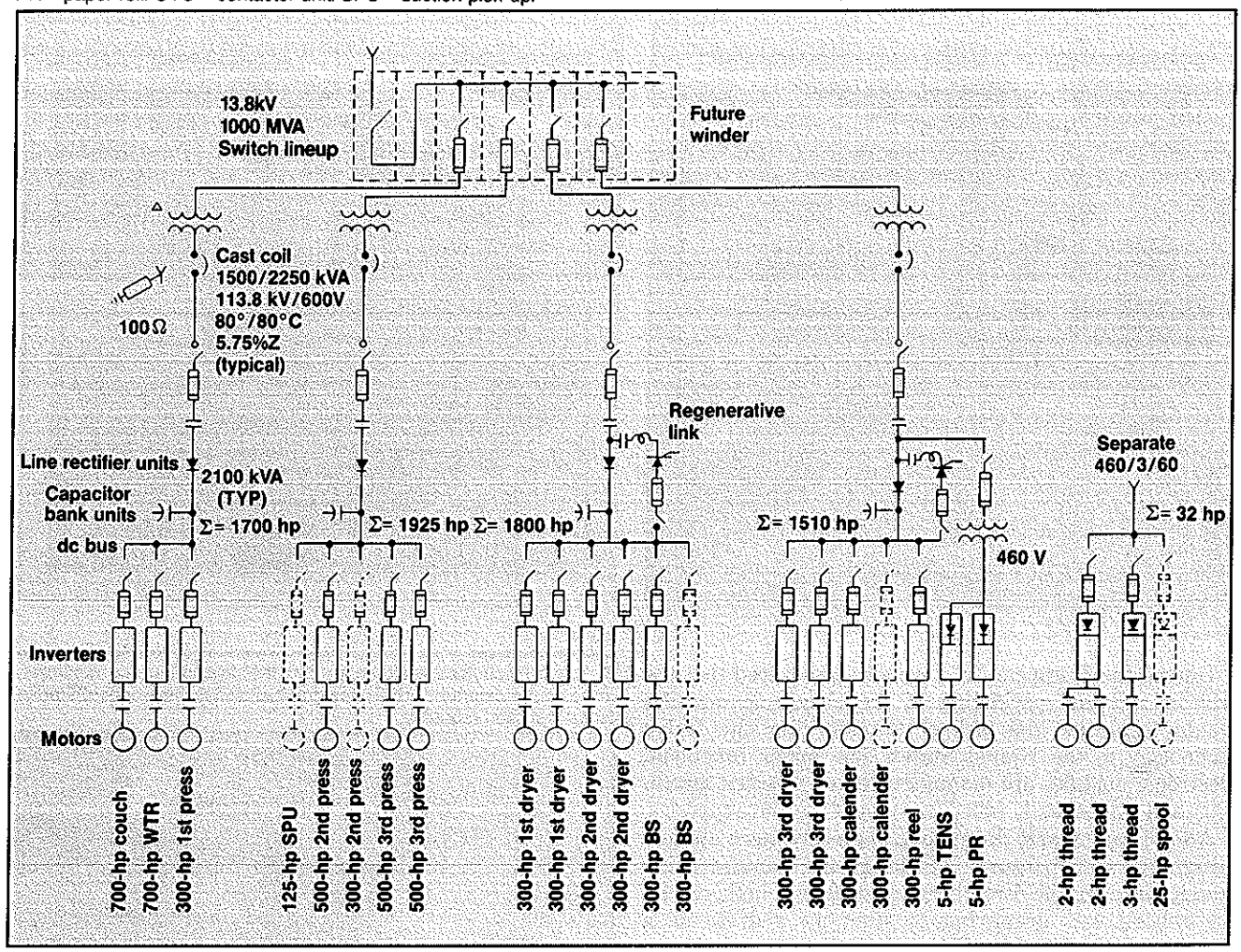
Motor, hp	*Amperage per line*	
	575 V (ac)	*500 V (dc)*
150	180	308
250	275	512
500	538	994
700	752	1388
1000	1070	1980

The production of the No. 6 machine represents over 25% of the total tonnage of the Savannah mill. In the summer of 1986, management appropriated funds to replace the entire machine drive. The scope of the project included:

- A new electrical equipment complex with environmentally controlled air to prevent corrosion of the new electronic equipment
- A new 15-kV feeder and four new substations to serve the new drive
- A new drive system selected for possible future wet-end rebuilds and sized for a speed range of 152-790 m/min (500-2600 ft/min)
- New speed reducers and jackshafts sized for 790 m/min.

An ac drive was to be considered within the existing schedule, budget, and construction limitations. Technological risks were to be kept to a minimum. The 13-month schedule required that the new drive be ready for installation during a 21-day shutdown in the fall of 1987. The engineering contract was awarded to Simons-Eastern Co. in late August of 1986. All equipment specifications

5. Simplified electrical single-line diagram of the No. 6 paper machine. WTR = wire turning roll. BS = breaker stack. TENS = tension roll. PR = paper roll. CTU = contactor unit. SPU = suction pick-up.



were issued for bids by late September.

Fact finding in Europe

In September 1986, we spent ten days in Europe visiting Stromberg plants in Helsinki and drive installations in Finland, Sweden, Austria, and Switzerland. We found a number of advantages in the ac drive.

First, the primary advantage is the more rugged motor with lower maintenance, lower repair costs, and the absence of a motor cooling duct. Higher efficiencies are available in ac motor designs than in dc motors. This efficiency advantage more than offsets the losses of the additional static power converter required for an ac drive.

Improved power factors are a characteristic of this type of ac drive. As illustrated in **Fig. 2**, the ac drive has a constant power factor of about 98%. The typical dc drive's power factor is less than 92% at 100% speed, and further deteriorates with a decrease in speed.

Lower line currents are drawn from the power system as a result of the constant higher power factor, as illustrated in **Fig. 3**. This lower current results in lower line and transformer losses. This reduction in power loss is often quite important, since many machines operate at only 65–85% of design top speed much of the time.

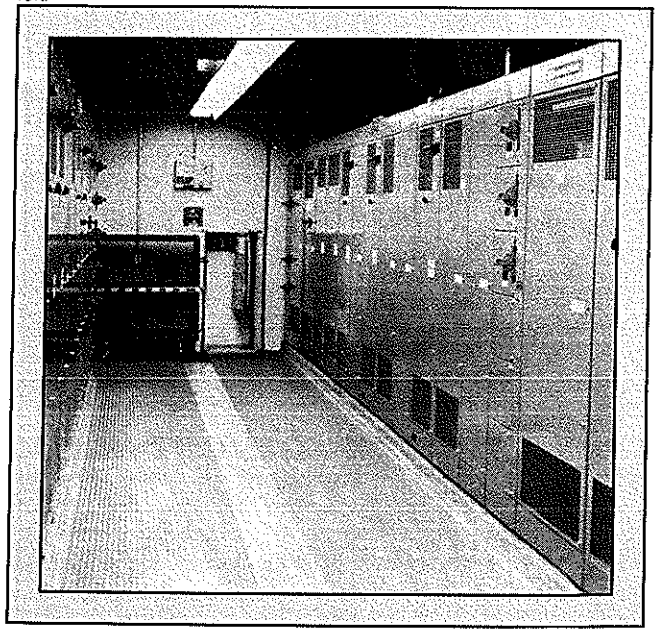
Lower harmonic currents are introduced to the power system, as illustrated in **Fig. 4**. This advantage is due to the lower line current, because the harmonic content is a function of fundamental current.

At the same rated voltages, ac motors have approximately 62% of the line current of dc motors. As **Table I** shows, the required cable amperage capacity for a 500-V dc motor is approximately 185% that of a 575-V ac motor; therefore, smaller cables are required for ac motor feeder circuits. A 250-hp dc motor would require a 4/C 500 MCM cable, whereas a 3/C 400 MCM cable could serve a 250 hp ac motor. Overall, the wiring cost of an ac drive is less than half that of the wiring material and labor costs of a dc drive.

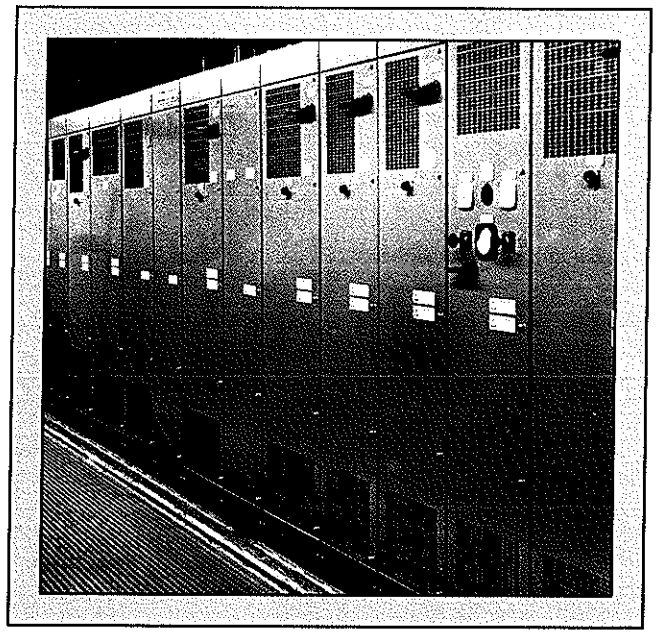
Fewer transformers (13.8 kV to 600 V) may be required for an ac drive. Some drive manufacturers not only limit the number of dc drives on a single transformer to six but also limit the ratio of the largest motor to the smallest motor rating. These limitations do not apply to an ac drive of this type.

These advantages result in lower installation, operating, and maintenance costs. In addition to less maintenance on the ac motor, each of the other advantages should be considered in the economic evaluations when an engineer is considering an ac drive.

6. In this photo of the drive equipment room, two wet-end bus line-ups are on the right. One of the two dry-end bus line-ups is on the left.



7. In this photo of the drive equipment room, the second dry-end bus line-up is on the right.



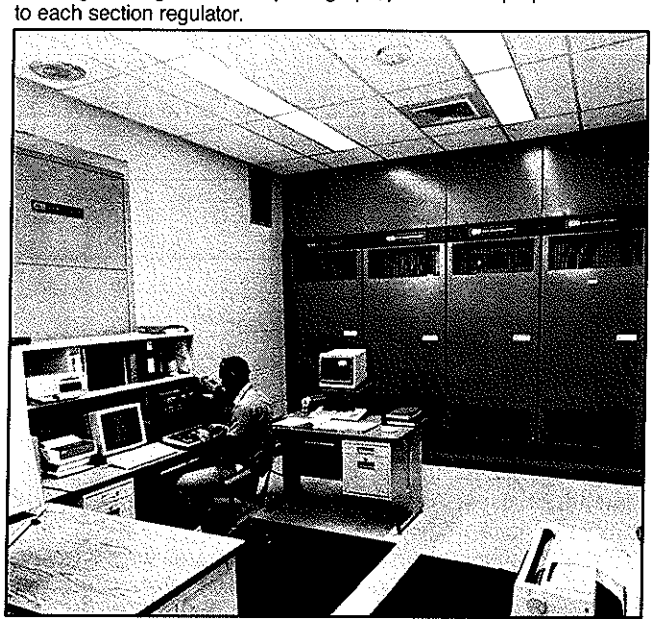
During the European trip, we also discovered that the "roll-in, roll-out" packaging of the electronic modules would minimize the risk of transferring this drive technology to the United States. The major functional electronic modules are manufactured on wheeled assemblies and can be easily rolled in or out of the drive cubicles.

Allen-Bradley and Stromberg engineers were already designing a system to meet U.S. design and manufacturing standards using the Stromberg technology. Furthermore, Stromberg was preparing to start up a drive on a linerboard machine in Finland similar to our No. 6 machine in Savannah. Also, Stromberg recently received the order for a large German newsprint machine drive larger than our No. 6 machine. The newsprint machine's top speed was 1500 m/min, and it was to start up sooner than our Savannah machine.

When we returned to Savannah, we strongly recommended that an ac drive be applied to the No. 6 machine. While bids were received from major drive suppliers on the basis of dc drives, Allen-Bradley/Stromberg was asked to submit an alternative proposal for an ac drive. The initial cost of an ac drive is greater than the cost of a dc drive. However, the evaluated cost of an ac drive is often lower when installation costs, motor repair expense, and power system advantages are considered.

Management supported the recommendation, and an order was placed for an ac drive in mid-November for a delivery in July 1987. This allowed the engineering and construction to proceed on schedule.

8. In the electronics equipment room, the drive reference controller, in the right background of the photograph, provides the proper reference to each section regulator.



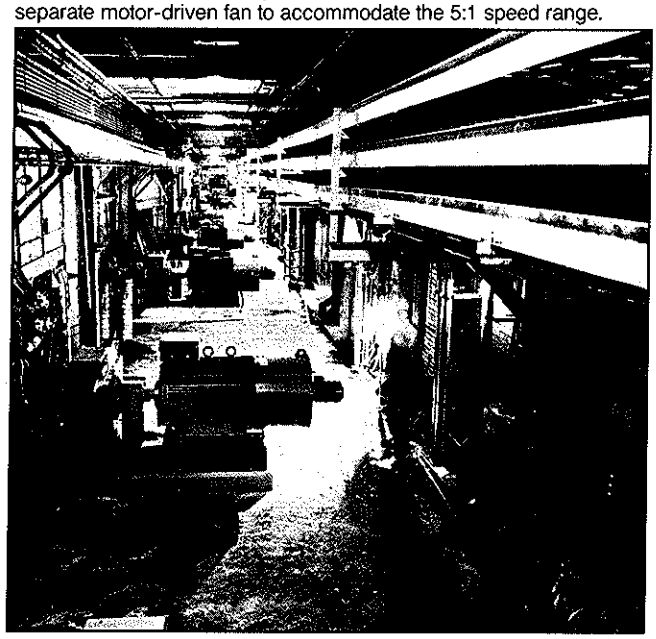
Application and design engineering

Configuration

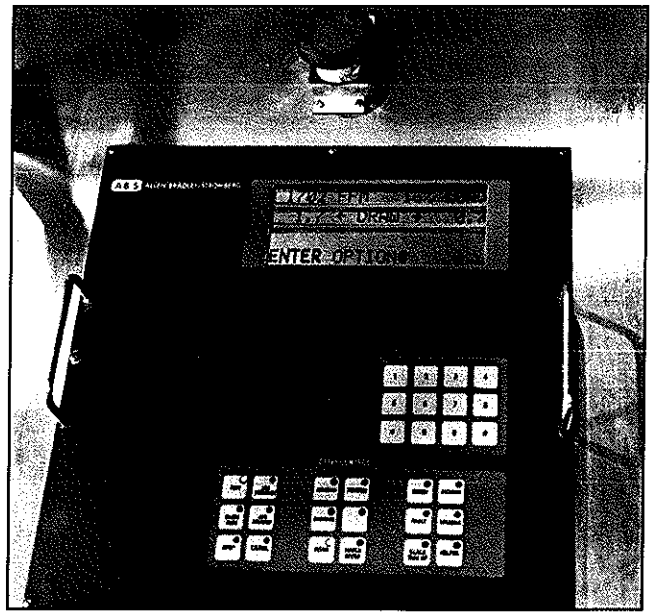
The configuration of the ac drive and the single line diagram is similar to a modern dc digital drive (**Fig. 5**). The four substations supply 575-V ac power to four drive line-ups. The 60-Hz power is converted to a constant-voltage dc bus by the line rectifier units. Each ac motor is provided adjustable-frequency ac power by individual pulse-width-modulated inverters. The capacitor bank units maintain the dc bus voltage during inversion. Each inverter has a vector-controlled digital regulator. Each motor has a high-resolution speed sensor.

The rectifier, capacitors, and inverters are located in the drive room, as **Figs. 6** and **7** show. A drive reference controller provides the proper reference to each section regulator, as well as overall diagnostics and color-graphic displays. The reference controller and its associated personal computers and diagnostic displays are located in

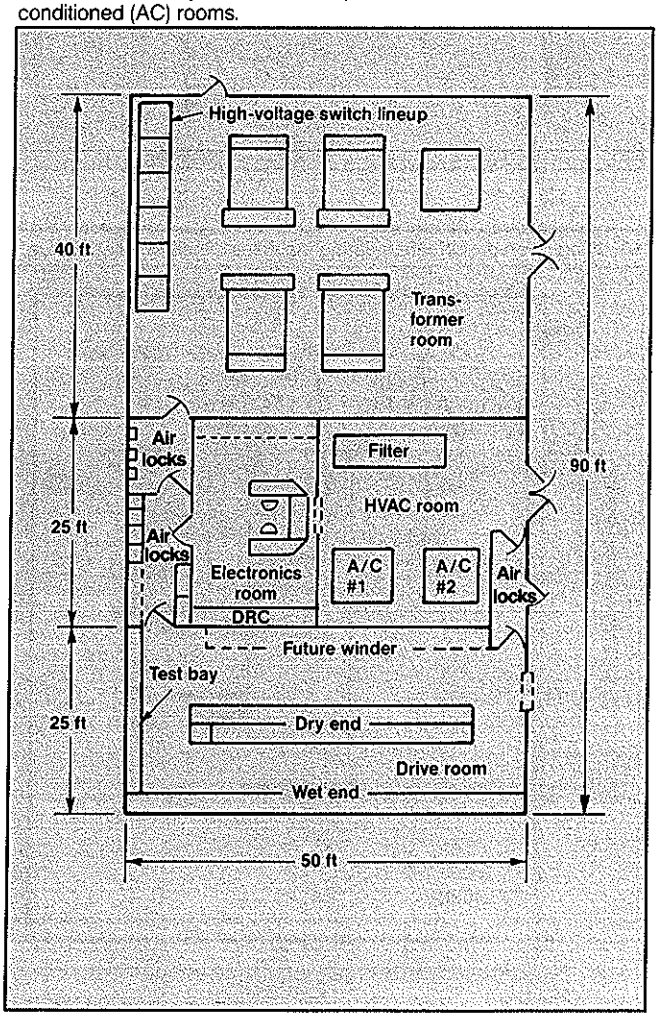
9. On the machine drive aisle, the ac drive motors are six-pole, cast-iron, rib-constructed, totally enclosed, fan-cooled machines with a separate motor-driven fan to accommodate the 5:1 speed range.



10. Operator's drop-in control station, mounted in the benchboard in the tending aisle



11. In the electrical equipment complex, three airlocks (AL) protect the environmentally controlled air spaces, in which there are two air-conditioned (AC) rooms.



the electronics equipment room (**Fig. 8**).

System engineering and sizing

The specifications for application engineering and equipment sizing were also similar to those required for a dc drive.

Motor ratings were selected by conventional TAPPI methods. Dryer motors were specified for 200% torque for 90 s, and all motors and controls have 1.15 service factors. Since the machine speed range is greater than 3:1, separate motors drive the motor cooling fans (**Fig. 9**).

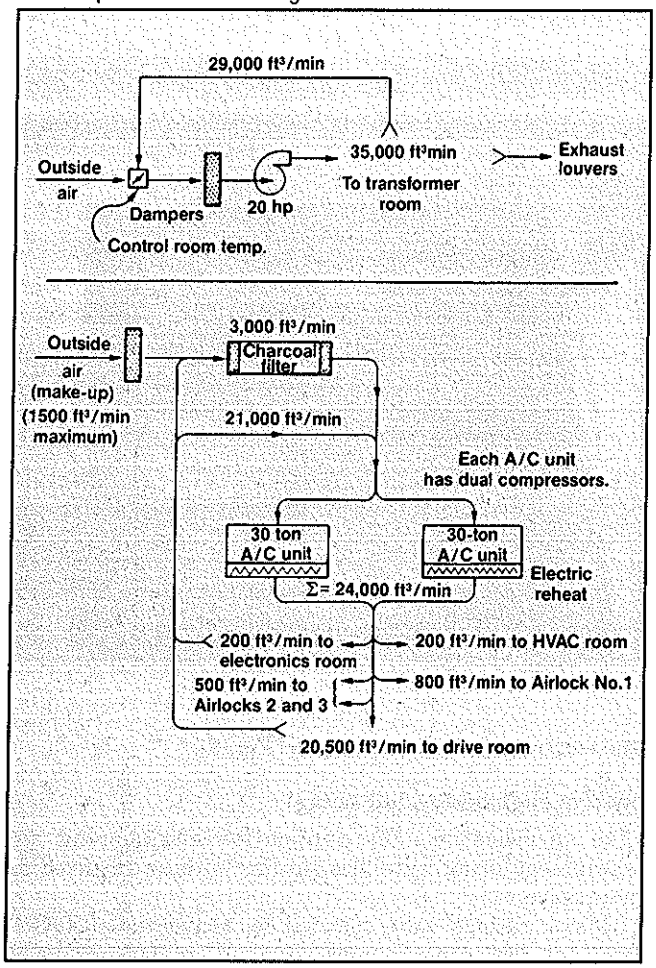
The pulse-width-modulated inverters were sized by the manufacturers to match the motor requirements. These inverters use gate turn-off thyristors with fiber-optic firing circuits.

The substation sizes were selected to match the line rectifier unit rating that had been selected to meet the acceleration requirements and normal running loads of the associated drives. Dry-end sections have gate turn-off thyristor line-generating units to provide a regenerative link back to the ac line for braking or overhauling loads.

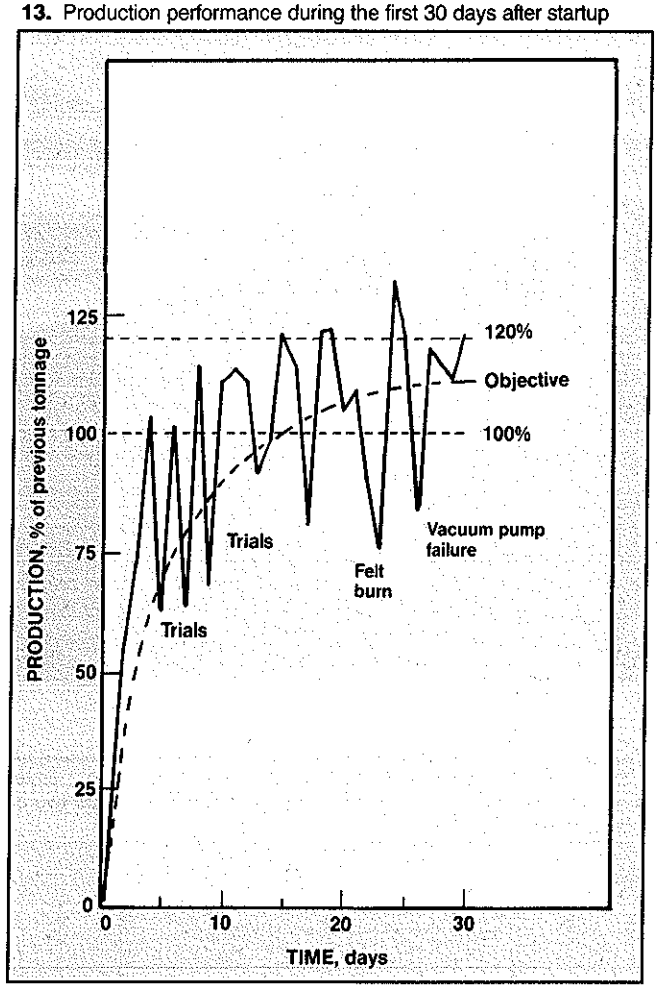
The gearing, gear-in speeds, and the specifications of shaft torsional frequencies were similar to those for a dc drive. The six-pole motor gear-in speeds are approximately 1200 rpm. A 12-Hz or greater torsional frequency was specified for all shafts and couplings.

Extensive drive system diagnostic features were specified. These include operator diagnostics and diagnostic tools for the drive technician. Most diagnostic troubleshooting, as well as all drive tune-up, is conducted from computer terminals in the electronics room (Fig. 8) rather than from the drive cabinets. This arrangement provides a quiet and far safer environment for trouble-shooting. The drive can also communicate over telephone lines (via computer modems) with the system design engineers at the factory. Should problems develop, these engineers would then have almost the same capabilities

12. Simplified HVAC flow diagram



13. Production performance during the first 30 days after startup



over the modem as they would within the electronics room.

The operators' controls consist of intelligent "drop-in" panels and color graphics which communicate with the drive system by serial data links (**Fig. 10**). These panels may be changed-out while the system is operating.

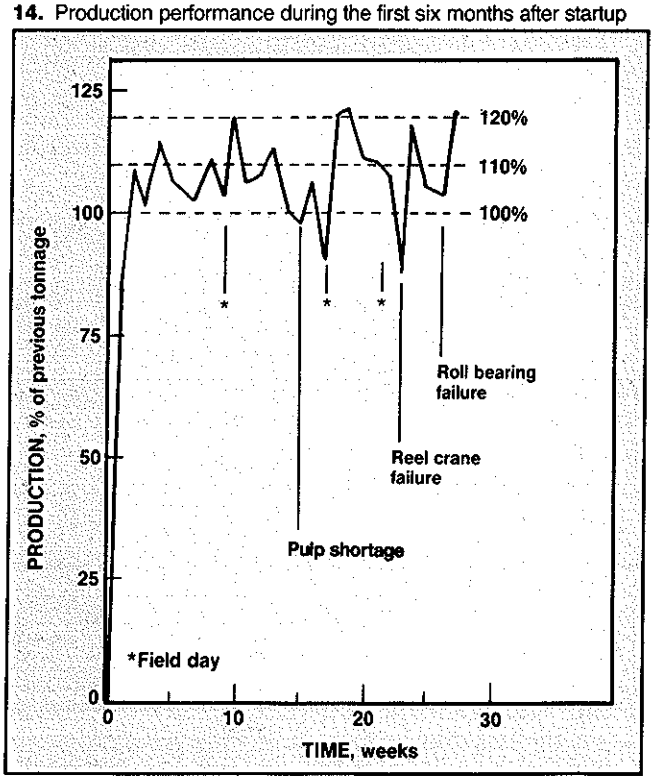
The displays allow the machine operator to play a key role in identifying any suspected drive problem. Valuable time is no longer lost while an operator determines that an electrical problem has occurred, calls for an electrician, and waits for diagnosis. Instead, the system makes a diagnosis and involves the operator and the electrician in a joint effort to respond quickly and effectively.

Design engineering

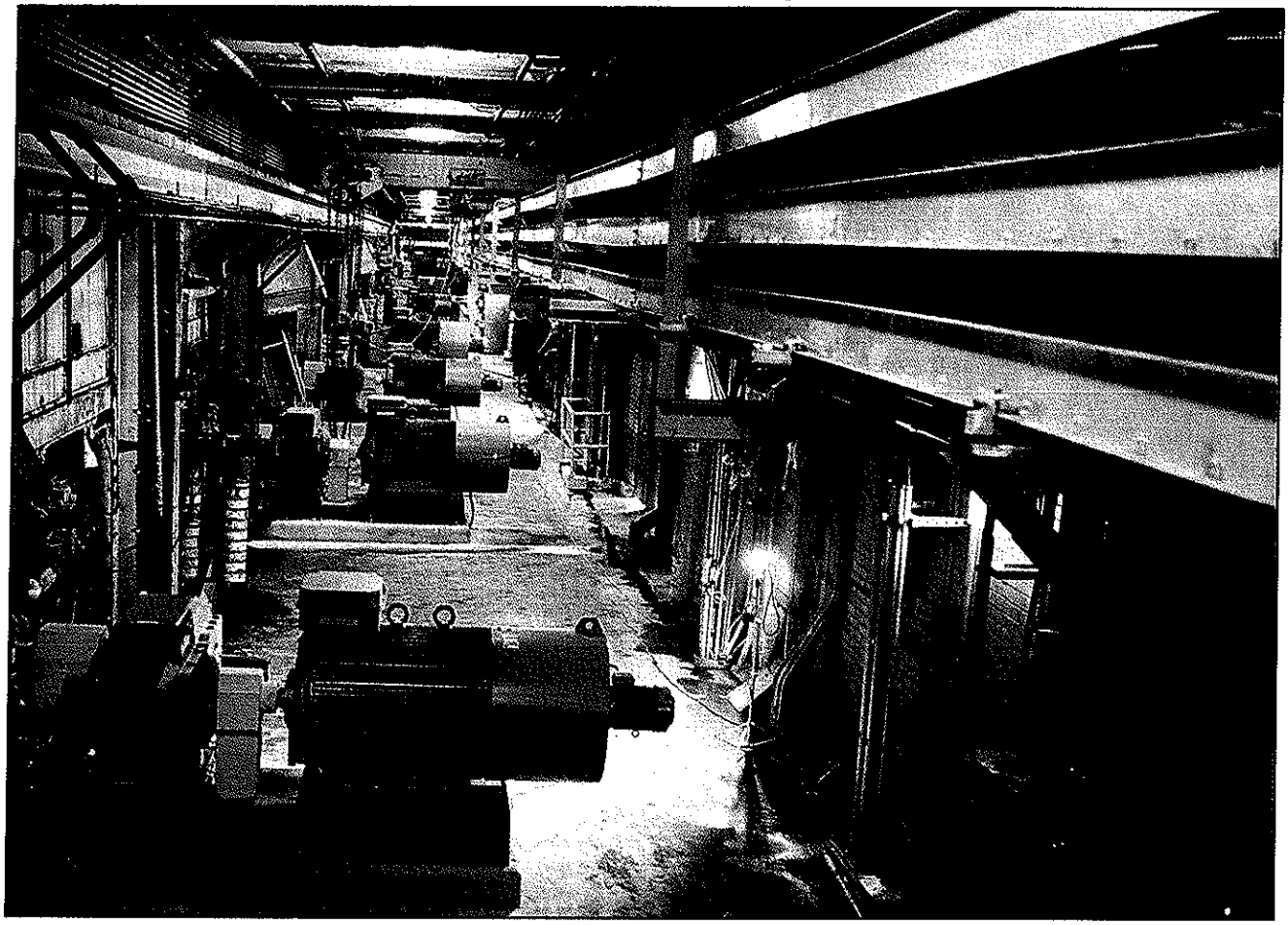
The space requirements and equipment layout for an ac drive are similar to those for a dc drive (**Fig. 11**). The No. 6 machine drive electrical complex is identical in size to that installed in 1984-1985 for a machine of similar size with a digital dc drive. The electrical complex has a force-ventilated transformer room and a set of air-conditioned rooms.

The air-conditioned rooms consist of an electronics room, a drive room, and a room for heating, ventilation, and air conditioning (HVAC) equipment. These rooms are also humidity controlled. All makeup air and a portion of the return air are filtered through a deep-bed charcoal filter (**Fig. 12**). Total room air is exchanged about every 75 s,

14. Production performance during the first six months after startup



15. In the drive aisle are the totally enclosed, fan-cooled ac motors, the prime advantage of ac drives



and the set points are 24°C and less than 45% relative humidity.

Construction

Engineering proceeded expeditiously from December 1986 through April 1987, with the building contract awarded in March 1987 and the electrical contract awarded in early May 1987. All contracts, including engineering, were awarded on a firm-price basis.

The building complex, with HVAC, was constructed in two months. The entire electrical construction required three months, and the drive system was installed in only one month. Fire and safety protection systems were in place before any equipment was energized. The HVAC system was in service for corrosion protection before the drive was delivered and installed.

Throughout the design, manufacturing, and construction period, our engineers worked closely with the equipment supplier engineers in the design and development of the drive, operator's panel, and test procedures. In addition, Allen-Bradley/Stromberg engineers worked closely with the consulting and design engineers to ensure that a correct design was delivered on time to the construction contractors. Simons Eastern design and field engineers were on site to assist the contractors during construction, checkout, and startup.

Preshutdown checkout

As far as it was practical, the entire drive was thoroughly checked-out prior to shutdown. The tests, checkout, and startup schedules and procedures required close cooperation.

Subsystem factory tests were conducted under load and duty cycles at Stromberg's Helsinki plant. Since this was the first drive designed for the United States, the tests were more extensive than normal.

System combination tests were conducted under load with a motor at Allen-Bradley's Cedarburg, Wis., plant. All hardware, firmware, and software were verified in these tests.

Both Allen-Bradley service personnel and Union Camp electricians were trained in Cedarburg before the drive was shipped. These individuals had the primary responsibility for installation, checkout, startup, and maintenance.

All spare parts were shipped within 30 days of drive delivery so they would be on-site for checkout and startup. A complete preshutdown checkout was conducted on the entire drive system with all motor and controls temporarily installed and connected near the final locations.

Finally, the entire drive system was energized, roughly tuned, and operated for four weeks before shutdown.

Shutdown and startup

A 21-day shutdown of the machine was scheduled to begin November 1, with startup scheduled for the morning of November 22.

The shutdown to install the new drive system included replacing two calender stacks. The shutdown schedule was dictated by the mechanical construction required. Although the mechanical construction fell as much as three days behind schedule, the electrical checkout went smoothly, and the startup was accomplished three days ahead of schedule.

The drive installation involved:

- Setting the 20 bedplates for the motors and gears
- Installing the 7 operator benchboards
- Installing 3 operators' controls in existing panels
- Wiring all electrical equipment.

In addition to the new drive, an AccuRay Thermoprofiler™ and a Fibron™ tail threading system were installed.

The final drive regulator tune-up included matching the response times of all sections, a final adjustment of slack takeup, draw, acceleration-deceleration rates, and a final checkout of all prescribed functions. Final tune-up of the tension regulators was performed after startup.

The machine started up smoothly and without incident the evening of November 19, 1987. During the first two days of operation, typical, minor problems were encountered. Electrical problems included (a) broken and loose connections, (b) relay coil failure, and (c) one printed circuit card failure on a paper roll.

Mechanical problems were: (a) indrive jackshaft interference, (b) paper roll gear failure, and (c) reel crane outage. Process problems entailed: (a) pulp mill problems, (b) water in dryer cans, (c) problems with press clothing, and (d) the "learning curve" on the new calender.

Performance

The machine rebuild did not include any wet-end changes or any significant dryer changes. The two high-stack calenders, with interstage dryers, were replaced with a new single-nip calender and the old reel was relocated. These machine changes were done for improved quality rather than for tonnage increases. We expected that the new drive would provide improved drive accuracies and availability. The existing drive steady-state speed regulation was a marginal ± 0.1%. The new drive has a speed regulation of ± 0.01%.

The start-up "learning curve" was projected as:

- 40% production on Day 2
- 70% production on Day 5
- 90% production on Day 10
- 100% production on Day 15
- 110% production on Day 30.

Here, 100% production represents the average production prior to shutdown.

The actual production following startup is shown in **Figs. 13** and **14**. The machine production reached normal levels on Day 4 after start-up and was on full "computer optimization control" less than five days after startup. The best day's production since startup was 133%, and the best week was 122%.

There have been no significant component failures in the new drive system during the first six months of operation and essentially no electrical drive or regulator problems. None of the lost machine time since the rebuild can be attributed to the new ac drive technology.

The entire project was completed successfully, within the budget, and ahead of schedule. This success required the close cooperation of the design engineering firm, equipment suppliers, and contractors, as well as that of mill operators and maintenance personnel.

The new drive system has exceeded all expectations as to accuracy, uptime, and performance. The speed-draw accuracies, response times, and operator features equal or exceed the performance of any modern digital dc machine drives. The ease of maintenance exceeds that of current dc digital machine drives.

Conclusions

For paper machines, ac drive technology is expected to be the standard of the 1990s. Based on the success of the drive on our No. 6 machine in Savannah, we may well have purchased our last dc machine drive. The ac machine drives will certainly be the major consideration for future paper machines.

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